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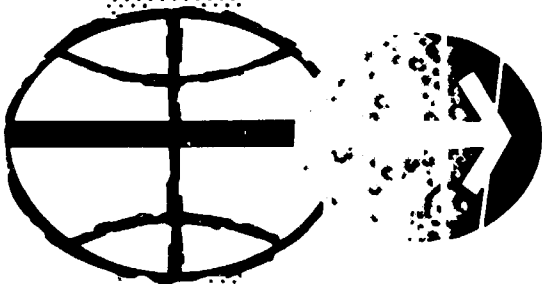
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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A SIMULATION STUDY TO EVALUATE BACKUP ENTRY

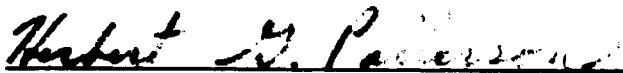RANGING SCHEMES FOR EARTH ORBITAL MISSIONS

MANNED SPACECRAFT CENTER

HOUSTON, TEXAS

July 26, 1968

PROJECT APOLLO

A SIMULATION STUDY TO EVALUATE BACKUP ENTRY RANGING SCHEMES FOR EARTH ORBITAL MISSIONS

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SUMMARY

A piloted simulation of CM Block II earth orbital entry has been conducted to evaluate various backup ranging schemes that could be used in the event of a primary G&N malfunction. The results of the study show that the scheme that combines Entry Monitor System ranging and Bank-Reverse-Bank ranging (Hybrid scheme) provides the best method for backup ranging. Simulation results show that if a complete G&N failure is detected before or after .05g's and the hybrid scheme is used for backup ranging, then the miss distance dispersions will be as follows:

   a. Mean radial = 21.5 nm (nautical miles)

   b. Standard deviation = 12.7 nm

INTRODUCTION

The EMS scrolls for the Apollo Block II earth orbital missions were designed for CM L/D values from .3 to .4. The range guidelines displayed on these scrolls are based on a model including a L/D of 0.34 and S/C weight of 11,000 lb, which was the nominal L/D and weight of the S/C at the time the scrolls were developed. Since that time, the range of L/D limits for subsystem design have been changed to .25 to .40 (reference 1) and the weight of the CM has increased considerably. The response of the S/C becomes more "sluggish" with respect to lift vector orientation as the L/D is lowered and at the lower limits, the guidelines could become difficult, if not impossible, to fly. Because the range guidelines are a function of both L/D and weight, a simulation was required to determine if the lines were still valid for the revised L/D and weight. Another, and probably the most important, reason to perform a man-in-the-loop simulation was to determine just how well the pilots can target using the EMS as a backup ranging device for earth orbital missions. A simulation study of entry ranging using the CM Block II EMS was performed in 1966 (ref. 2). However, this simulation considered only lunar return entries. It did, of course, give some insight as to how well the pilots can target but at the beginning of the present subject study, there had not been a piloted simulation study using the EMS as a backup ranging device for earth orbital missions. There were also a variety of proposed schemes as to how to fly the EMS during backup ranging maneuvers and also some schemes that did not use the EMS. In order to evaluate the relative advantages of the various backup ranging schemes and to resolve the uncertainties concerning the use of the EMS as a backup ranging device, the G&CD has performed the subject man-in-the-loop simulation study.

LIST OF SYMBOLS

a	Acceleration, ft/sec^2
a_x	Acceleration along X_b, ft/sec^2
C_A	Axial aerodynamic coefficient
C_N	Normal aerodynamic coefficient
$C_{M_{ref}}$	Pitching moment coefficient (reference point)
$C_{M_{aero}}$	Pitching moment coefficient (aerodynamic point)
D	Reference diameter, ft
f	Fuel, lb
G_{EMS}	Acceleration measured by the EMS, ft/sec^2
g	Acceleration of gravity, ft/sec^2
h	Altitude, ft
I_{xx}, I_{yy}, I_{zz}	Moments of inertial about X_b, Y_b, Z_b, slugs-ft^2
I_{xy}, I_{xz}, I_{yz}	Products of inertia, slugs-ft^2
K_D	Resolution factor from X_b axis to stability axis
K_R	Conversion factor from nautical miles to feet, n mi/ft
L_j, M_j, N_j	Jet moments about the X_b, Y_b, Z_b axis, ft-lb
p, q, r	Spacecraft rotational rates about the X_b, Y_b, Z_b axis, deg/sec
$\bar{q}$	Dynamic pressure, lb/ft^2
$R_{.05g}$	Range-to-go at .05g's, n mi
t	Time, sec
V_{Ems}	Velocity measured by the EMS, ft/sec
V_0	Initial EMS velocity, ft/sec
V_R	Total relative velocity, ft/sec
$V_{.05g}$	Velocity at .05g's, ft/sec
X_b, Y_b, Z_b	Spacecraft body axes
X_{cg}, Y_{cg}, Z_{cg}	Spacecraft center of gravity in the X_b, Y_b, Z_b axis system, in.
σ	Standard deviation
Θ, Ψ, ϕ	Euler angles
η	Total angle of attack, deg
ρ	Atmospheric density, slugs/ft^3

LIST OF ABBREVIATIONS AND ACRONYMS

A/D	Analog to Digital
AGCES	Apollo Guidance and Control Evaluation Simulation
BMAG	Body Mounted Attitude Gyro
BRB	Bank Reverse Bank
cg	Center of Gravity
CM	Command Module
D/A	Digital to Analog
DDA	Digital Differential Analyzer
EMS	Entry Monitor System
FCSD	Flight Crew Support Division
FDAI	Flight Director Attitude Indicator
G&CD	Guidance and Control Division
G&N	Guidance and Navigation
L/D	Lift to Drag
NR	North American Rockwell Corporation
PGNCS	Primary Guidance, Navigation, and Control System
PIPA	Pulse Integrating Pendulous Accelerometer
RCS	Reaction Control System
RSI	Roll Stability Indicator
RTCC	Real Time Computation Center
RTG	Range to Go
S/C	Spacecraft
SCS	Stabilization and Control System
SPS	Spacecraft Propulsion System

SIMULATION IMPLEMENTATION

General

The implementation of the Block II CM EMS entry ranging simulation was accomplished by coupling a hybrid solution of the S/C equations of motion to a fixed base simulation of the CM. This is referred to as the Apollo Guidance and Control Evaluation Simulation (AGCES). A complete and detailed description of the AGCES, including S/C equations of motion, software simulation of hardware, use of prototype hardware in the hybrid computer-hardware interface, and special purpose interface equipment used for systems interface, is presented in reference 3. A block diagram of the equipment interface and signal flow are shown in figure 1 to indicate the fidelity of the simulation.

Characteristics of Simulated Vehicle

The vehicle considered was an entry configuration of the Apollo Block II CM. The static aerodynamics and mass properties used in the simulation are presented in tables I and II, respectively. The simulation runs were terminated at an altitude of 100,000 ft. Since at this altitude the S/C is still well up in the supersonic velocity range, the aerodynamics were varied as a function of angle-of-attack but not as a function of Mach number. The small changes in the mass properties due to RCS fuel usage, heat shield ablation, etc. were not considered in the simulation. The cg location presented in table II is for an L/D value of .28. However, the L/D was varied during the study from a 3σ low of .25 to a 3σ high of .375. This was done by changing the cg along the Z_b axis as shown in figure 2.

The nominal atmosphere that was used in the simulation was the 1962 Standard (reference 4). However, the atmosphere was also varied from a -3σ (30°N) to a $+3\sigma$ (30°N) for some of the data runs (figure 3).

EMS Simulation

A detailed description of the EMS is presented in reference 3. The EMS used in the simulation was not, however, a production item and a description of the essential features is in order. The simulated EMS was comprised of all the essential parts that make up the hardware EMS, such as G-V plotter, roll stability indicator, range-to-go counter, corridor verification lights, threshold indicator (.05g light), slew switch, and mode selector switch. These items were modifications of "off-the-shelf" equipment and were positioned in the CM mockup in their relative positions on the main display console (figure 4). The item of real interest was the simulated G-V drive unit (figure 5). It essentially was a modification of a compact strip chart recorder. The synchronous motor used to drive

the strip chart was replaced with a positional DC tape drive servo-mechanism and driven by the calculated EMS velocity as follows:

$$V_{EMS} = V_{.05g} - K_D \int a_x dt$$

The strip chart recorder stylus was driven in the vertical direction by the calculated S/C X_b acceleration.

$$G_{EMS} = a_x /32.17$$

The strip chart itself consisted of pressure sensitive paper and represented the EMS scroll. The pattern used in the simulation was the earth orbital non-exit entry pattern shown on figure six.

The RTG counter was a digital readout display and was driven by the following calculation.

$$R_{EMS} = R_{.05g} - K_r \int (V_{.05g} - K_D \int a_x dt)dt$$

This calculation was mechanized on analog equipment and because of the double "open-ended" integration, an independent check was performed at the beginning of each day of operation. The accuracy of this calculation on the analog equipment was good to ± 1 percent. This was considered sufficient since the hardware specification requires only ± 3 percent. However, the anticipated performance of the actual RTG counter is $\pm .25$ percent (reference 5). The effects of the simulated EMS accuracy as compared to the anticipated accuracy on the results of the simulation are discussed in the Discussion of Results section of this report.

TEST PROCEDURES

General

In the event of a G&N failure or a violation of the EMS lines during the entry portion of the earth orbital missions, the EMS can be used to perform backup ranging to a given target location. However, there are various ways of flying the EMS and also, there are other backup ranging schemes which do not use the EMS. The schemes that were evaluated in the simulation were:

    a. EMS Backup Ranging

    b. Bank-Reverse-Bank Ranging

    c. Hybrid Scheme

Three pilots were used as test subjects for these studies. Prior to data runs, each pilot was given ample training time to become familiar with the three backup ranging schemes.

Pilot Procedures

All the simulation runs were started at an altitude of 400,000 ft with various initial conditions (IC) and target locations. Before the runs were started, the simulation pilot checked the cockpit to insure that all the essential switches were in the correct position. He then initiated the simulated EMS. In order to initialize the simulated EMS Roll Stability Indicator (RSI), he placed the EMS ROLL switch in the up position. Then, with his right hand, he pushed the GDC ALIGN button and while the GDC ALIGN button was depressed, he used his left hand to rotate the YAW ATTITUDE SET thumbwheel until the RSI was pointed to zero (up). He then released the GDC ALIGN button and placed the EMS ROLL switch in the down position. The PITCH, YAW, and ROLL ATTITUDE SET were then positioned to zero using the appropriate thumbwheels. The GDC ALIGN button was pressed again to align the FDAI(1). At this point, the pilot was given (via voice link) the EMS range-to-go (RTG) number and the EMS scroll was set to V_0 SET and the small knob above the scroll thumbwheel (also marked V_0 SET) was moved to the right. Then, using the EMS thumbwheel, he set the scroll to 37,000 ft/sec. The pilot exercised some care during this procedure since the simulated EMS scroll would not back up. The small knob was moved to the left and the scroll was slewed to the EMS velocity using the negative (bottom) slew switch. Care in this operation was necessary because the positive EMS scroll slew did not work in the simulation. The Mode Selector switch was positioned to the RNG SET position and the RTG number was slewed into the RTG counter. The pilot then placed the Mode Selector switch to the ENTRY position. The pilots also received additional voice transmitted information before the runs started. This information varied depending on which backup ranging scheme he was to fly (discussed in detail later). The pilot was then given, via voice link, the word "operate" and the run began. At the beginning of the run, the pilot threw the EVENT TIMER switch to the START position. During normal operations the event timer would have been started earlier, however, all the information the pilot received during a simulated run was based on the event timer reading zero at an altitude of 400,000 ft. The correct status of the operational simulator displays, switches, and controls at the beginning of the run are presented in table III. All other displays, switches, and controls were positioned in their normal operating condition in accordance with the Apollo Operational Handbook (AOH) for continuity.

At .05g's the .05g light illuminated and the pilot threw the three BMAG MODE switches to the RATE 2 position (up). He then positioned the EMS ROLL and the .05g switches to the on position (up). At this time, he started maneuvering the S/C with the RHC. As soon as the g load started to build, the following switches were thrown: FDAI SCALE 50/15 50/10 (down), ATT DEAD BAND MAX (up), and RATE HIGH (up). At this point, if there had been a G&N failure (MASTER ALARM light on), he would attempt to fly the S/C to the designated target using whichever backup ranging scheme he had been instructed to fly for that run. However, if the G&N was still operating correctly, he would continue to fly the S/C in the SCS mode using the G&N roll attitude error signal on the FDAI (this mode is commonly called

Manual G&N). He continued to fly this mode and monitor the EMS until the MASTER ALARM light came on or there was a violation of the EMS g limit lines. If this situation occurred, he took over the run and completed the entry using the designated backup ranging technique. If the MASTER ALARM light did not come on and there was no violation of the g limit lines, the pilot continued to fly the manual G&N mode to the end of the run (100,000 ft latitude). However, he was instructed to indicate (via voice link) if he felt that the G&N was guiding the S/C to some target other than the one given to him prior to entry.

There were three backup ranging tehcniques that were studies in the simulation: (a) EMS backup ranging, (b) Bank-Reverse-Bank ranging, and a combination of (a) and (b) called the (c) Hybrid Scheme.

EMS Backup Ranging. - When this scheme was used for backup ranging, the pilot was given the following information prior to the start of a simulated run:

  (a) EMS RTG number, n m

  (b) EMS scroll velocity, ft/sec

  (c) Target roll contour line angle, deg

  (d) Target crossrange error, n m north (+) or south (-)

The procedure the pilot used to fly the EMS backup ranging scheme after .05g's (assuming a G&N failure prior to .05g) was to first roll the S/C so that the RSI was positioned at the roll contour line angle and in the direction of the target crossrange error (RSI to the pilot's left was lift vector to the north). (The contour lines are positions in the maneuver footprint that the S/C can reach by holding a constant roll angle and then reversing the roll angle at a given time.) Once this contour roll angle was attained by the pilot, he held it until the g level reached approximately 1g. At this point, he modulated the lift vector until the range guidelines were in agreement with the RTG counter. He attempted to hold a constant g level to the end of the run making small adjustments to the g level as the G vs V trace passed through successive range guidelines. It should be noted that if the pilot modulated the lift vector indicator on only one side of the RSI meter, the S/C would of course fly away from the center line of the footprint. Therefore, depending upon what the target crossrange error was, the pilot reversed the RSI from time to time during the run. Since there was no crossrange error display in the S/C, these reversals were made by the pilot intuitively time integrating the g loading in the crossrange direction. In addition, he knew that the maximum crossrange that could be obtained was approximately +80 nm which was also helpful in determining when to reverse the RSI orientation. The pilots were instructed to perform all these reversals by rolling the S/C through lift up (RSI = 0) since it was much easier to "kill off" additional range than to gain it.

Bank-Reverse-Bank Ranging. - When this scheme was used for backup ranging, the pilot was given the following information prior to the start of a simulation run:

(a) EMS RTG number, nm

(b) EMS scroll velocity, ft/sec

(c) Target roll contour line angle, deg

(d) Time to reverse the roll angle, min-sec

The procedure the pilot used to fly the BRB ranging scheme after .05g (assuming G&N failure prior to .05g) was to roll the S/C so that the FDAI(1) roll bug was pointed at the roll contour line angle. All the information given to the pilot for the scheme was based on the initial S/C direction to be left (lift vector south) regardless of where the target was located. The pilot then held this roll attitude until the event timer reached the time to reverse bank. At this time, the pilot rolled the S/C through zero roll (lift up) and attained the same roll attitude on the other side of the FDAI(1). This attitude was then held to the end of the run.

Hybrid Scheme. - When this scheme was used for backup ranging, the pilot received the same information as that received for the BRB scheme.

The procedure the pilot used to fly the hybrid scheme after .05g's (again assuming a G&N failure prior to .05g's) was identical to the EMS scheme except that the pilot would modulate the lift vector on the pilot's right side of the RSI meter (lift south) until the event timer reached the time to reverse the roll angle. At this time, he reversed the lift (north) and continued to fly the range guidelines to the end of the run.

There was no additional instructions or procedures given to the pilot for failures that occurred after .05g except that he should continue to try to reach the target. However, if the pilot had been instructed to use the BRB ranging scheme and there was a G&N failure, he was instructed not to use the EMS range guidelines for backup ranging.

Initial Conditions and Target Locations

All the simulation runs began at the same position as follows:

Altitude	400,000 ft
Longitude	97.84°W
Latitude	31.18°N
Azimuth	79.479°

From this initial position, there were six different conditions of inertial flight-path angle and inertial velocity (figure 7). Condition number one was the nominal entry position on the SPS target line for the 205 mission (S/C 101). There were also pre-calculated footprints for each of the six entry conditions. In each of the footprints there were seven target locations representing recovery forces in the footprint (figure 8). The targets were located on various roll angle contour lines. For each of the IC's and targets, there were pre-calculated values of: initial velocity, inertial flight path angle, target longitude, target latitude, bank angle, time to reverse bank angle, EMS velocity at .05g's, EMS RTG at .05g's, and crossrange to the target (table IV). This data was calculated by the Mission Analysis Branch of MPAD and transmitted to the G&CD before the simulation study began (reference 6). With the six different IC's and seven targets for each IC, there were 42 different entries that could be simulated.

Recorded Data

Data was recorded for each flight on: two eight-channel strip chart recorders, two X-Y plotters, and a digital line printer. The information displayed and associated scaling of the data gathering equipment was as follows:

Eight-Channel Recorder (A)

Total relative velocity, V_R ---------------0 $\longrightarrow$ 500,000 ft/sec

Total aerodynamic acceleration, a -----------0 $\longrightarrow$ 10g's

Dynamic pressure, $\bar{q}$ ----------------0 $\longrightarrow$ 500 lb/ft^2

Roll RCS moment, L_j ------------------ $\pm$1250 ft-lb

Pitch RCS moment, M_j ------------------ $\pm$1250 ft-lb

Yaw RCS moment, N_j ------------------ $\pm$1250 ft-lb

RCS fuel, f ------------------0 $\longrightarrow$ 100 lb

Altitude, h ------------------0 $\longrightarrow$ 500,000 ft

Eight Channel Recorder (B)

Roll rate, p ------------------ $\pm$25 deg/sec

Pitch rate, q ------------------ $\pm$25 deg/sec

Yaw rate, r ------------------ $\pm$25 deg/sec

Euler angle, ϕ ------------------ $\pm$250 deg/sec

Euler angle, θ ------------------ $\pm$250 deg/sec

Euler angle, ψ ------------------ $\pm$250 deg/sec

Commanded roll angle ------------------------------ ±250 deg

Roll gimbal angle ------------------------------ ±250 deg

30 in. by 30 in. X-Y Plotter (Double Pen)

Altitude (ft) vs longitude (deg)

Latitude (deg) vs longitude (deg)

15 in. by 10 in. X-Y Plotter (Single Pen)

Total acceleration (g) vs EMS velocity (ft/sec)

Digital Line Printer (End Conditions at 100,000 ft altitude)

Total Run Time (t), sec

Latitude, deg

Longitude, deg

Inertial velocity components, ft/sec

Total relative velocity, ft/sec

TEST SCHEDULE

General

To completely evaluate the three backup ranging schemes, the test schedule was broken down into four failure categories:

(a) Complete G&N failures prior to .05g's

(b) Complete G&N failures after .05g's

(c) Erroneous G&N signals causing g limit line violations

(d) Erroneous G&N signals with no limit line violations

A variety of IC's and target locations were used for each category of failure to insure that the pilots did not become too familiar with any one entry trajectory. In addition, the L/D and atmosphere were varied to study their effects on the three backup ranging schemes. A detailed run schedule including: run number, type of run, backup mode, pilot, IC, L/D, atmosphere, and target location is presented in table V.

Complete G&N Failures Prior to .05g's

The first category of runs (1 through 78) assumed that a G&N failure (MASTER ALARM light on) had occurred prior to .05g's and that the S/C was aligned in the correct entry altitude at the beginning of the run (altitude = 400,000 ft). The pilots flew runs 1 through 50 using the three backup ranging schemes with nominal values of L/D and atmosphere. Runs 51 through 78 incorporated 3 σ high and 3 σ low values of L/D and atmosphere.

Complete G&N Failures After .05g's

The second category of runs (79 through 84) were initially flown in the manual G&N mode. At some point after .05g's, a complete G&N failure was introduced (MASTER ALARM light on) and the pilots took over the entries and continued to try and reach the target using the predesignated backup ranging scheme.

Erroneous G&N Signals Causing g Limit Line Violations

These runs (85 through 87) were also initially flown in the manual G&N mode. When the g level began to build up, an erroneous steering command was introduced (lift down) that caused a violation of the g limit lines. Here again the pilots took over the entry and continued to try and reach the target.

Erroneous G&N Signals With No Limit Line Violation

This run (88) began with the pilot flying in the manual G&N mode. Erroneous steering signals were introduced that led the S/C to a target other than the one originally designated. However, these erroneous signals did not violate the EMS limit lines. In this case, the pilot continued to follow the G&N commands to completion of the run regardless of whether he thought they were correct or not.

DISCUSSION OF RESULTS

General

The discussion of results is divided into the same four failure categories as the TEST SCHEDULE.

(a) Complete G&N failures prior to .05g's

(b) Complete G&N failures after .05g's

(c) Erroneous G&N signals causing g limit line violations

(d) Erroneous G&N signals with no limit line violations

In addition, there are two supplemental categories entitled:

(e) Typical trajectory time histories

(f) Pilot evaluations

Primarily, the performance criteria used for evaluation of the test results was how well the pilots could range to the target. However, the amount of fuel used and the pilot's evaluation of the backup ranging scheme are also presented.

Complete G&N Failures Prior to .05g's

The results of the study of complete G&N failures prior to .05g's, using the three different backup ranging schemes, are based on 78 runs made by three pilots. Runs 1 through 50 assume nominal conditions, while runs 51 through 78 include $\pm 3\sigma$ variations in both L/D and atmosphere. The results of these runs in terms of target miss distance in longitude and latitude and the amount of fuel used from .05g's to an altitude of 100,000 ft are presented in table V. The miss distance errors are presented at an altitude of 100,000 ft and not at the target. This was accomplished by comparing the simulation end conditions to a G&N guided trajectory at an altitude of 100,000 ft for a given IC and target location. Since the G&N guidance does not fly the lift vector in the same way as the BRB and Hybrid schemes, there are additional errors in the latitude direction presented in table V. This can be seen since most of the runs using these schemes terminated south of the G&N guided trajectory. It should be noted that the miss distances are presented as errors in latitude and longitude and not as downrange and crossrange error. This was done for ease of data reduction and since the azimuth of the S/C was close to 90° at the end of the runs (i.e., approximately due east). The errors imposed are small and nonexistent when the radial or root-sum-squared (RSS) values are used. Another point that should be noted is that the simulated EMS had an accuracy of ± 1 percent. This means that the RTG counter could have a ± 1 percent error at the end of the run, thereby producing a ± 1 percent error in the miss distances. For example, if the nominal value of RTG (1109 nm) was entered in the RTG counter and the pilot flew the range guidelines correctly, he could miss the target by as much as ± 11.1 nm due to the RTG counter error. This one percent accuracy in the simulator RTG counter was considered sufficient since the specification for the flight hardware requires an accuracy of only ± 3 percent. However, NR has stated that the anticipated accuracy of the flight hardware RTG counter will be as low as $\pm .25$ percent (reference 2). If this turns out to be the case, then the miss distances presented in this report are very pessimistic and should be diminished by from six nm to 15 nm in longitude depending on the magnitude of the number entered into the RTG counter.

The data for the nominal values of L/D and atmosphere (runs through 50) using the three backup ranging schemes were statistically evaluated and are presented in table VI as the mean and standard deviation (1 σ) for longitude, latitude, and radial miss distances. Also included are the mean, 1 σ , maximum, and minimum values for fuel usage. It can be seen that the BRB scheme gave slightly better results (mean = 21.1 nm, 1 σ = 11.3 nm) compared to the EMS scheme (mean = 23.5 nm, 1 σ = 15.5 nm) and Hybrid scheme (mean = 21.4 nm, 1 σ = 13.7 nm). As a matter of fact, with nominal L/D and atmospheric conditions, it might be expected that the BRB scheme would give even better results than those obtained in the simulation. This probably would have been the case _if_ the bank angle and time-to-reverse bank angle information, which was transmitted to the pilots, came from the subject simulation. If this were true, it would simply be a test as to how well the AGCES would repeat itself; however, this was not the case. The BRB information came from a six-degree-of-freedom digital program (reference 6) and was considered to be RTCC data. The AGCES then simulated the real-time situation with the BRB information being transmitted to the pilot prior to entry (see Pilot Procedures section). In this sense, the BRB miss distances for nominal values of L/D and atmosphere can be considered to be the difference between the simulated world and the real world.

The BRB scheme also used less fuel (mean = 30.4 lb, 1 σ = 5.2 lb) than either the EMS scheme (mean = 46.1 lb, 1 σ = 15.3 lb) or the Hybrid scheme (mean = 40.5 lb, 1 σ = 17.0 lb). However, none of the schemes used enough fuel to deplete even one RCS. This was true regardless of when a G&N failure occurred or the type of G&N failure. Therefore, the amount of fuel used by the different schemes was eliminated as part of the criteria to evaluate the best backup ranging scheme. Of course, if a portion of the CM RCS fuel is used for deorbit during a mission, then a decision must be made by the pilot to either use a ranging scheme (automatic or backup) or simply hold the S/C at a given bank angle and conserve fuel.

From the previous discussions, it seems that the BRB scheme is slightly better for backup ranging than the other two schemes as long as the L/D and atmosphere remain nominal. However, this is definitely not the case when +3 σ off-nominal conditions of L/D and atmosphere are introduced (cases 51 through 78). Table VII presents the mean values of longitude, latitude, and radial miss distances for the three schemes when +3 σ variations of L/D and atmosphere are encountered during entry. The L/D 3 σ high and 3 σ low used were .375 and .25, respectively. The atmospheric 3 σ high and 3 σ low used were taken at 30° N latitude and are presented in figure 3. Table VII shows that the miss-distances using the BRB scheme increased considerably due to both +3 σ values of L/D and atmosphere, while the miss-distance values using the EMS and Hybrid schemes reamined within the same radial miss distance as was experienced with nominal values of L/D and atmosphere. This should be expected since the BRB scheme has no method of correcting for off-nominal condition. However, when the EMS is used, the pilot correlates the g value with the RTG counter and by modulating the S/C roll angle, he can obtain the correct

g level and the effect of off-nominal L/D and atmosphere can be elimi-
nated. Of course, the effect of off-nominal L/D can also be eliminated
with the BRB scheme if the pilot flies a 90° contour angle. However, some
of the effect of off-nominal atmosphere would still be present and the
deorbit burn must be scheduled for a 90° target. Therefore, any underburn
or overburn would land the S/C away from the target.

Complete G&N Failures After .05g's

When the pilots used either the EMS (runs 79 and 89) or hybrid schemes
(runs 83 and 84), the resulting miss distances from complete G&N failures
after .05g's were essentially the same as G&N failures prior to .05g's.
However, this is only true if the malfunction occurs rapidly without erro-
neous steering commands. In the simulation, this malfunction was portrayed
to the pilot by illuminating the MASTER ALARM light and the termination of
G&N commands. In these cases, the pilot was following a nominal G&N entry
up to the time of the failure. When the malfunction occurred, the pilots
simply took control and completed the entry using the EMS range guidelines.
The transition between the guided entry and the EMS backup entry causes no
control problems and in all cases, the pilot was able to correlate the
range guidelines with the RTG counter. It should be noted that the Hybrid
scheme and the EMS scheme are really the same for this type of failure.
That is, the same technique is used for backup entry; namely, the EMS
scheme. The Hybrid scheme cannot be used unless the failure occurs imme-
diately after .05g's since the guidance also starts generating commands
at this point, thereby driving the S/C to a different trajectory than the
Hybrid scheme would produce. Also, unless the target is on the extreme
edge of the maneuver footprint, the best assumption at the time of the
failure is that the G&N guidance has already taken out the crossrange error.
The pilot would then intuitively time-integrate the g loading in the cross-
range direction to hold the crossrange error to a minimum.

When the pilots used the BRB scheme (runs 81 and 82), the resulting
miss distances from complete G&N failures after .05g's were essentially
what would be expected--erratic. It, of course, depends on just how close
the G&N trajectory happens to be to the BRB trajectory for a given entry
when the failure occurs. In one case, the pilot held the backup bank angle
and landed within 20 nm of the target (run 82); while in another case, the
pilot landed 58 nm from the target (run 81).

Erroneous G&N Signals Causing g Limit Line Violations

There were only three runs flown with erroneous G&N signals which
caused g limit line violations. When the g limit line violation occurred,
the pilots took over the run and continued to try and reach the target
using one of the three backup ranging schemes. (run 85 used the EMS scheme,
run 86 used the BRB scheme, and run 87 used the Hybrid scheme). When the
violation occurred and the pilot used either the EMS or Hybrid schemes, he

would take over the entry and fly lift-up until the range guidelines were in agreement with the RTG counter. He then flew the rest of the entry using the EMS scheme. However, as might be expected, in some cases there just was not enough ranging capability remaining to get the RTG counter and the range guidelines to agree. In these cases, the S/C landed short of the target. If the target was near the "heel" of the maneuver footprint and the g limit line violation occurred early in the entry, the pilot would have a good chance of maneuvering the S/C to the target using the EMS. However, if the target was near the "toe" of the footprint or the g limit line violation came late in the entry, the S/C would land short of the target. In case 85, the pilot flew full lift-up subsequent to the violation and still landed 81 nm short of the target. In case 87, he flew lift-up and was able to recover and land only 10 nm short of the target. These miss distances are not really a measure of the ranging technique since its simply a function of whether or not the S/C has enough capability to reach the target after a g limit line violation. If it does, then the EMS can be used to do the ranging and if it doesn't, then there isn't any ranging scheme that will work.

When the BRB scheme was used for backup ranging subsequent to a g limit line violation, the pilots were in a complete quandry as to how to range to the target. As was mentioned in the Pilot Procedures section of this report, the pilots were told not to use the EMS when the BRB scheme was used for ranging. Therefore, after a g limit line violation, they had no onboard ranging information. The only way they could possibly reach the target was by intuition or luck.

Erroneous G&N Signals With No Limit Line Violations

This case (run 88) did not involve a violation or backup ranging. It was a situation where the pilot was informed that the target was on the 70° contour line and the G&N guided him to a 30° contour line target. It didn't take long for the pilot to realize that something was wrong since the EMS trace did not pull enough g's. However, he was instructed to continue to fly the G&N unless there was a G&N failure indicated. In this case, the S/C overshot the target by 377 nm. This case was put in the test only to show that some of the worst miss distances can occur when there are no violations or G&N failure indications. The indications to an experienced pilot in this case were obvious due to the large targeting error introduced. For smaller errors, the indications are not so obvious and a general rule for takeover cannot be reliably formulated where an EMS violation does not occur.

Typical Trajectory Time Histories

Figure nine shows typical trajectory time histories of velocity, acceleration, RCS moments, fuel, altitude, S/C rates, S/C attitude, commanded roll angle, and actual roll angle. These time histories are for the nominal

S/C 101 entry interface conditions of inertial velocity (25,700 ft/sec) and flight path angle (-1.6°). The target point was located on the 55° contour angle with no crossrange error. There was a G&N failure prior to .05g's and the pilot flew the entry with the hybrid scheme. It can be seen from the time history of roll gimbal angle, that the pilot held approximately 55° roll angle on one side for half the flight and then reversed to the other side and continued to fly the EMS range guidelines. If the pilot had flown the entry using the BRB scheme, the time history of the roll angle would be exactly 55° on one side and exactly 55° on the other side. Also, if he had flown the EMS scheme, the roll angle would be close to 55° but there would be a number of reversals from one side to the other.

Figure ten shows an EMS G vs V trace for the above mentioned case, flown with the hybrid scheme. It can be seen that the hybrid scheme produces a fairly smooth G vs V trace. Of course, for shorter targets the G level would be higher and for longer targets, the G level would be slightly lower. The G vs V trace using the EMS scheme would be essentially the same as long as the IC and target location remained the same. One trait which is prevalent when the EMS or hybrid schemes are used is the smooth G vs V trace with fairly constant distribution of energy. Because of this, the peak G level is held to a minimum. However, this is not the case when the BRB scheme is used. The G vs V trace is smooth but the G level "peaks out" at some point and does not have as even a distribution of energy as does the other schemes. Because of this, the peak G is usuall, higher using the BRB scheme. It would be impractical to present all the time history and G vs V data for all the runs; however, these data are available and can be obtained from the author if necessary.

Pilot Evaluation

In general, the pilots seemed to like the idea of using the EMS as a backup ranging device. In fact, they gave both the EMS and Hybrid scheme a Cooper rating of from 2 to 3 (reference 7). They like the hybrid scheme somewhat better than the EMS scheme since the crossrange error was taken out by the time-to-reverse the bank angle, thereby leaving more time to concentrate on the range guidelines or downrange error. They also preferred targets that were near the center of the maneuver footprint. For short targets, the pilots had a tendency to "dive" the G level down to correlate the G level with the RTG counter. This would produce a G overshoot and the pilots would then have to fly lift-up to reach the target. Also, for long targets, if the pilots tried to correlate the G level with the RTG counter early in the entry, they would sometimes cause a G overshoot and again have to fly lift-up to reach the target. However, the miss distances for these cases were about the same as for targets in the middle of the maneuver footprint indicating that the pilots were able to correct for these G overshoots.

The pilot task involved in flying the BRB scheme is relatively simple, since all he had to do was hold a roll attitude and reverse this attitude at the time-to-reverse. However, the pilots did not particularly care for this scheme since there was no provision for adjustment. The pilots were aware that off-nominal conditions would cause dispersions in the landing point and they felt that any backup ranging scheme should have a method to correct for these conditions.

CONCLUSIONS

1. For complete G&N failures prior to .05g's:

   a. With nominal values of L/D and atmosphere, the miss distances using the BRB scheme are slightly better than the EMS or Hybrid schemes.

   b. The BRB scheme uses less fuel than the EMS or Hybrid schemes. However, none of the schemes used enough fuel to deplete one RCS.

   c. When $\pm 3 \sigma$ variations of L/D and atmosphere are encountered, the miss distances using the BRB scheme increase considerably, while the miss distances using the EMS and Hybrid schemes remain the same.

   d. L/D effects can be eliminated from the BRB scheme by flying to a 90° contour angle. However, some of atmospheric effects will still be present and the deorbit burn must be scheduled for a 90° target.

2. For complete G&N failures after .05g's"

   a. If the EMS is used for ranging, the resulting miss distances remain the same as G&N failures prior to .05g's.

   b. If the BRB scheme is used, the miss distances will be erratic and it would only be a random occurrence if the S/C landed close to the target.

3. If a complete G&N failure is detected before or after .05g's and the Hybrid scheme is used for backup ranging, then the miss distance dispersions will be as follows:

   a. Mean radial = 21.5 nm

   b. Standard deviation = 13.7 nm

4. Erroneous G&N signal causing g limit line violations:

    a. If the S/C has enough capability to reach the target, the EMS range guidelines can be used to range to the target.

    b. When the BRB scheme is used, the pilot has no onboard ranging information and therefore, it would only be a random occurrence if he landed close to the target.

5. Some of the worst miss distances can occur when the G&N commands erroneous signals and there are no limit line violations or G&N failure indications.

6. The EMS and Hybrid schemes have a more even distribution of energy than the BRB scheme.

7. The simulation pilots liked the Hybrid scheme somewhat better than the EMS scheme because the crossrange error was taken out by reversing the bank angle.

8. The simulation pilots did not care for the BRB scheme because there was no provision for adjustment of the entry.

RECOMMENDATIONS

1. The Hybrid scheme be used as the prime backup for all earth orbital missions provided there is ground tracking information available to initialize the EMS.

2. The Hybrid scheme be called EMS ranging to avoid confusion.

REFERENCES

1. Contract Change Authorization: Contract No. NAS 9-150,
       CCA No. 1655, Master Serial No. 150-2834. September 12, 1967.

2. MSC Internal Note No. 67-EG-10: A Simulation Study of Entry
       Ranging Using the CM Block II Entry Monitoring System (EMS).
       January 25, 1967.

3. Apollo G&C Evaluation Simulation Data Book. July 1967.

4. NASA, USAF, USWB: U. S. Standard Atmosphere, 1962. December 1962.

5. Handouts at EMS review presented by NR to MSC on March 5, 1968.

6. MSC Memorandum 68-FM53-61: Support Data for Guidance and Control
       Division's Entry Monitor System Hybrid Simulator Test.
       February 14, 1968.

7. MSC Memorandum CF131-8M-167: Engineering Simulation Study of the
       Entry Monitor System. March 20, 1968.

TABLE I. – S/C 101 STATIC AERODYNAMICS HYPERSONIC MACH RANGE

η	$\cos \eta$	C_A	C_N	$C_{M_{Ref}}$	$C_{M_{Aero}}$
110.1365	−0.3442	−0.1879	0.3686	−0.2099	0.02862
115.1365	−0.4247	−0.3308	0.3182	−0.1610	0.04491
120.1365	−0.5020	−0.4706	0.2709	−0.1178	0.05750
125.1365	−0.5755	−0.6095	0.2225	−0.0770	0.06698
130.1365	−0.6446	−0.7335	0.1983	−0.0547	0.07362
135.1365	−0.7088	−0.8634	0.1819	−0.0410	0.07671
140.1365	−0.7675	−0.9794	0.1687	−0.0328	0.07637
145.1365	−0.8205	−1.0828	0.1424	−0.0194	0.07275
150.1365	−0.8672	−1.1763	0.1202	−0.0103	0.06748
155.1365	−0.9073	−1.2672	0.0960	−0.0016	0.06052
160.1365	−0.9405	−1.3452	0.0748	0.0033	0.05170
165.1365	−0.9665	−1.4138	0.0526	0.0083	0.04234
170.1365	−0.9852	−1.4611	0.0305	0.0114	0.03114
175.1365	−0.9964	−1.4840	0.0115	0.0129	0.02034
180.1365	−1.0000	−1.4900	−0.0035	0.0137	0.01144
185.1365	−0.9960	−1.4840	−0.0185	0.0144	0.02429

Reference Area = S = 129.4 ft^2

Reference Diameter = D = 154.0 inches

Moment Center: X_{Ref} = 1141.25 inches

X_{Aero} = 1041.6 inches

Y_{cg} = 0.0

TABLE II. - MASS PROPERTIES OF THE S/C USED IN
THE SIMULATION (NOMINAL)

Weight   --------------------- 13068. lbs

Mass   --------------------- 406.2 slugs

$X_{cg_{AERO}}$ --------------------- 1041.6 in.

Y_{cg} --------------------- 0.0 in.

Z_{cg} --------------------- 5.57 in.

I_{XX} --------------------- 6250.1 slug-ft^2

I_{YY} --------------------- 6434.0   "

I_{ZZ} --------------------- 5851.2   "

I_{XY} --------------------- 60.2   "

I_{XZ} --------------------- -446.1   "

I_{YZ} --------------------- 51.9   "

TABLE III. - DESIRED STATUS OF OPERATIONAL DISPLAYS,

SWITCHES, AND CONTROLS AT BEGINNING OF RUN

A. EMS

    (1) .05g light ------------------------------ off
    (2) Corridor indicator light -------------- off
    (3) G-V plotter assembly
        G ------------------------------------ 0
        V -------------------------------------- Value from voice link
    (4) Roll attitude indicator --------------- up
    (5) RTG display --------------------------- Value from voice link
    (6) Mode selector switch ------------------ Entry

B. DISPLAYS

    (1) G meter ------------------------------- 0
    (2) FDAI (1)
        (a) Rate needles ------------------- 5/5
        (b) Attitude error needles --------- 5/5
        (c) Ball --------------------------- gimbal angles
        (d) Roll bug ----------------------- 0

C. SWITCHES

    (1) FDAI SCALE ---------------------------- 5/5 5/5
    (2) FDAI SELECT --------------------------- 1 (assumes loss of IMU)
    (3) FDAI SOURCE --------------------------- ATT SET
    (4) ATT SET ------------------------------- GDC
    (5) MANUAL ATTITUDE ROLL ------------------ RATE CMD
    (6) MANUAL ATTITUDE PITCH ----------------- RATE CMD
    (7) MANUAL ATTITUDE YAW ------------------- RATE CMD
    (8) LIMIT CYCLE --------------------------- OFF
    (9) ATT DEADBAND -------------------------- MIN
  (10) RATE ---------------------------------- LOW
  (11) DIRECT RCS ---------------------------- ON
  (12) SC CONT ------------------------------- SCS
  (13) CMC MODE ------------------------------ AUTO
  (14) ENTRY EMS ROLL ------------------------ OFF
  (15) ENTRY .05G ---------------------------- OFF
  (16) BMAG MODE ROLL ------------------------ ATT 1/RATE 2
  (17) BMAG MODE PITCH ----------------------- ATT 1/RATE 2
  (18) BMAG MODE YAW ------------------------- ATT 1/RATE 2

D. CONTROLLERS

    (1) CMD Rotational Hand Controller (RHC) -- detent
    (2) Translational Hand Controller (THC) --- normal

TABLE IV. – INITIAL CONDITIONS AND TARGET LOCATIONS

Inertial Velocity ft/sec	Inertial flightpath angle deg	Target long. W. deg.	Target lat. N. deg.	Bank angle (Roll left first) deg	Time to reverse bank angle, sec from 400K ft.	EMS Velocity at 0.05g ft/sec	EMS RTOGO at 0.05g n. miles	Crossrange to target n. miles
25,700	-1.6	65.11	31.87	55	363	25,804	1109	0
"	"	60.63	31.21	30	410	"	1356	0
"	"	67.36	32.19	70	346	"	959	0
"	"	70.60	32.4?	90	336	"	803	0
"	"	65.40	31.10	55	467	"	1103	45
"	"	69.40	32.80	82	287	"	870	27
"	"	62.50	32.30	42	280	"	1245	48
25,750	-1.2	56.12	30.38	55	472	25,839	1345	0
"	"	51.10	29.20	30	537	"	1632	0
"	"	59.30	31.00	70	453	"	1166	0
"	"	62.50	31.50	90	432	"	985	0
"	"	56.50	29.60	55	583	"	1337	51
"	"	61.10	32.00	81	338	"	1057	42
"	"	53.40	30.70	43	359	"	1486	60
26,000	-1.93	66.09	31.99	55	339	26,106	1141	0
"	"	61.20	31.30	30	384	"	1409	0
"	"	69.10	32.35	71	320	"	976	0
"	"	71.80	32.60	90	294	"	824	0
"	"	66.30	31.20	56	415	"	1138	48
"	"	70.60	33.10	80	235	"	891	36
"	"	63.50	32.50	43	254	"	1276	48
25,800	-.88	41.75	26.41	55	676	25,859	1718	0
"	"	36.00	24.25	29	740	"	2068	0
"	"	45.53	27.65	70	365	"	1489	0
"	"	49.40	28.80	90	361	"	1253	0
"	"	47.60	29.10	55	483	"	1716	57
"	"	42.20	25.60	81	282	"	1353	48
"	"	38.50	26.00	43	567	"	1903	42

TABLE IV. – CONCLUDED

Inertial Velocity ft/sec	Inertial flightpath angle deg	Target long. W. deg.	Target lat. N. deg.	Bank angle (Roll left first) deg	Time to reverse bank angle, sec from 400K ft.	EMS Velocity at 0.05g ft/sec	EMS RTOGO at 0.05g n. miles	Crossrange to target n. miles
25,500	-1.35	64.23	31.75	55	382	25,603	1080	0
"	"	60.00	31.10	29	426	"	1313	0
"	"	66.80	32.08	70	365	"	939	0
"	"	69.35	32.32	90	361	"	794	0
"	"	64.45	31.00	55	483	"	1077	48
"	"	68.20	32.80	81	282	"	856	36
"	"	62.00	32.10	43	322	"	1196	42
25,700	-2.4	73.95	32.62	55	256	25,816	858	0
"	"	70.14	32.37	30	285	"	1064	0
"	"	76.17	32.71	71	249	"	737	0
"	"	78.25	32.75	90	229	"	619	0
"	"	74.10	32.00	55	335	"	853	39
"	"	77.40	33.30	82	181	"	666	33
"	"	72.00	33.10	43	213	"	962	36

TABLE V. – RUN SCHEDULE AND RESULTS

Run No.	Type of Run	Backup Mode	Pilot	IC	L/D	Atmos.	Tgt.	Long. Error, N.M. − =Short, + =Long	Lat. Error, N.M. − = South, + = North	Fuel
1	a	EMS	1	1	N	N	1	−6.604	+2.160	30
2			1	1			3	−26.676	+9.720	24
3			1	1			4	−32.968	−5.940	51
4			1	1			5	−31.252	+21.060	46
5			1	1			7	−1.664	−13.860	63
6			1	3			3	−18.512	+1.680	22
7			1	3			5	−16.276	+21.840	20
8			2	4			1	−10.296	+1.380	46
9			2	4			2	−28.236	−18.660	56
10			2	4			4	+18.096	−12.420	58
11			2	4			5	−27.768	+1.740	36
12			2	4			6	+4.056	−23.760	48
13			2	5			3	−4.680	+16.740	67
14			2	5			7	+2.548	+45.660	30
15			3	6			1	+28.548	+1.440	38
16			3	6			2	−6.656	−29.880	38
17			3	6			4	−7.124	−4.680	56
18			3	6			6	+9.204	+0.720	84
19			3	6			7	−26.936	−8.580	54
20			3	2			2	−4.680	−0.780	52
21			3	2			6	−22.828	+12.240	47
22			3	2			4	+3.172	+10.320	47
23		BRB	2	1			1	−10.556	−16.860	26
24			2	1			2	+1.144	−11.580	27
25			2	1			3	−17.472	−12.720	24
26			2	1			4	−35.568	−12.900	29
27			2	1			6	+23.036	−15.120	38
28			2	3			6	+8.632	−13.260	31
29			2	5			4	+8.216	−23.340	38
30		HYB	1	1			1	−2.496	−17.820	27
31			1	1			2	−10.816	−15.120	20
32			1	1			3	−21.996	−14.760	16

TABLE V. – RUN SCHEDULE AND RESULTS (Continued)

25b

Run No.	Type of Run	Backup Mode	Pilot	IC	L/D	Atmos.	Tgt.	Long. Error, N.M. - =Short, + =Long	Lat. Error, N.M. - = South, + = North	Fuel
33	a	HYB	1	1	N	N	5	−20.800	+2.880	27
34			1	1			7	−38.480	−12.120	19
35			1	3			3	−12.168	−16.380	27
36			1	3			5	−14.560	+1.920	22
37			2	4			1	+7.748	−14.940	53
38			2	4			2	+8.783	−12.000	53
39			2	4			4	+21.372	−11.160	54
40			2	4			5	+31.252	−5.400	33
41			2	4			6	−20.384	−37.380	55
42			2	5			3	+28.600	+30.900	35
43			2	5			7	−36.400	−12.060	12
44			3	6			1	+15.600	−13.380	53
45			3	6			2	+1.196	−12.840	62
46			3	6			4	−3.224	−6.840	53
47			3	6			6	+3.796	−29.820	61
48			3	6			7	+1.716	−18.360	46
49			3	2			2	+6.240	−9.900	63
50			3	2			6	+4.264	−19.560	59
51		EMS	1	1	3 σ H	N	4	−8.840	−4.500	34
52			1	1			7	−15.132	+5.820	35
53			1	1	3 σ L		3	−20.956	−0.600	31
54			1	1			4	−34.164	+5.820	26
55			1	1			3	−7.748	+10.200	65
56			1	1			4	−14.248	−15.060	40
57		BFB	2	2	3 σ H		3	+46.228	−18.540	40
58			2	2			5	+52.728	−35.520	36
59			2	2	3 σ L		4	−55.796	−3.660	30
60			2	2			7	−136.188	−0.840	29
61		HYB	3	6	3 σ H		4	−0.520	−23.940	38
62			3	6			6	−12.636	+15.900	31
63			3	6	3 σ L		2	−14.560	−19.560	25
64			3	6			4	−36.608	−23.820	17

TABLE V. - RUN SCHEDULE AND RESULTS (Concluded)

Run No.	Type of Run	Backup Mode	Pilot	IC	L/D	Atmos.	Tgt.	Long. Error, N.M. - =Short, + =Long	Lat. Error, N.M. - = South, + = North	Fuel
65	a	HYB	3	6	3σL	N	2	+5.720	-14.760	63
66	↓	↓	3	6	↓	↓	4	-10.140	-4.680	60
67		EMS	1	1	N	3σH	3	+23.920	-18.540	60
68			1	1		↓	6	+17.004	+1.260	55
69			1	1		3σL	4	-21.736	+6.060	56
70		↓	1	1			5	-11.596	-6.780	40
71		BRB	1	1		3σH	1	+39.156	-17.520	28
72			1	1		↓	7	-0.468	-22.500	30
73			1	1		3σL	1	-48.724	-19.320	28
74		↓	1	1		↓	7	-91.572	-10.020	30
75		HYB	1	1		3σH	3	+27.768	-14.340	44
76			1	1		↓	6	+12.324	-12.240	39
77			1	1		3σL	4	-34.632	-23.760	43
78	↓	↓	1	1		↓	5	-30.420	-2.220	51
79	b	EMS	1	1		N	4	-1.092	+33.840	70
80		↓	1	1			2	+3.848	-25.860	60
81		BRB	2	1			4	-56.420	-11.880	58
82		↓	2	1			2	-9.932	-16.920	44
83		HYB	3	1			4	-15.444	+12.180	57
84	↓	↓	3	1			2	+22.204	-24.720	70
85	c	EMS	1	1			3	-80.860	+5.520	42
86		BRB	2	1			3	-39.936	+.540	40
87	↓	HYB	3	1			3	-19.864	+28.320	44
88	d	Long Tgt.	1	1	↓	↓	2	+376.792	-86.820	56

TABLE VI. - MEAN AND STANDARD DEVIATION MISS DISTANCES
FOR THE EMS, BRB, AND HYBRID BACKUP RANGING SCHEMES

		Backup Ranging Scheme		
		EMS	BRB	Hybrid
Longitude, n mi + Overshoot	Mean	− 9.4	− 3.2	− 2.4
	1 σ	16.2	18.2	18.4
Latitude, n mi + North	Mean	1.3	−15.1	−11.6
	1 σ	16.4	3.7	12.6
Radial, n mi (RSS)	Mean	23.5	21.2	21.5
	1 σ	15.5	11.3	13.7
Fuel, lb	Mean	46.1	30.4	40.5
	1 σ	15.3	5.2	17.0
Fuel, lb	Max	84	38	63
	1 σ	20	24	12

Note: All the above cases were flown with nominal
conditions of L/D and atmosphere.

TABLE VII. – OFF-NOMINAL L/D AND ATMOSPHERIC EFFECTS
ON THE THREE BACKUP RANGING SCHEMES

L/D Effects

Scheme	L/D	Mean Values		
		Longitude, n mi + Overshoot	Latitude, n mi + North	Radial, n mi
EMS	3σ H	-12.0	.7	13.1
	3σ L	-19.3	.1	22.3
BRB	3σ H	49.5	-27.0	56.7
	3σ L	-96.0	- 2.3	96.1
HYBRID	3σ H	- 6.6	- 4.0	22.1
	3σ L	-13.9	-15.8	23.8

Atmospheric Effects

Scheme	Atmos.	Mean Values		
		Longitude, n mi + Overshoot	Latitude, n mi + North	Radial, n mi
EMS	3σ H	20.5	-8.5	23.7
	3σ L	-16.7	- .4	18.0
BRB	3σ H	19.3	-20.0	32.7
	3σ L	-70.1	-14.7	72.3
HYBRID	3σ H	20.0	-13.2	24.2
	3σ L	-32.5	-13.0	36.3

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Figure 1. – Block diagram of equipment interface and signal flow

* FLIGHT HARDWARE
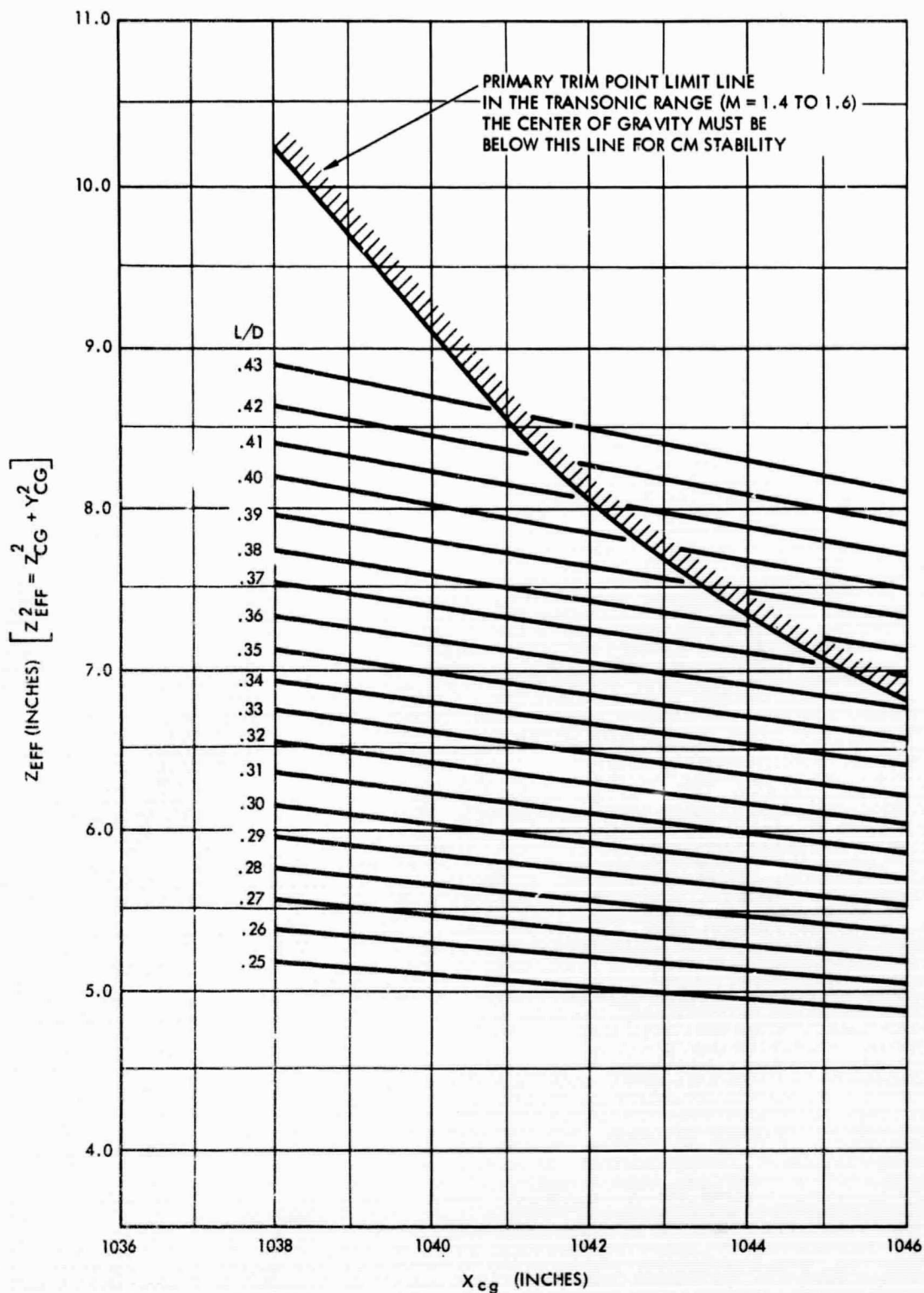
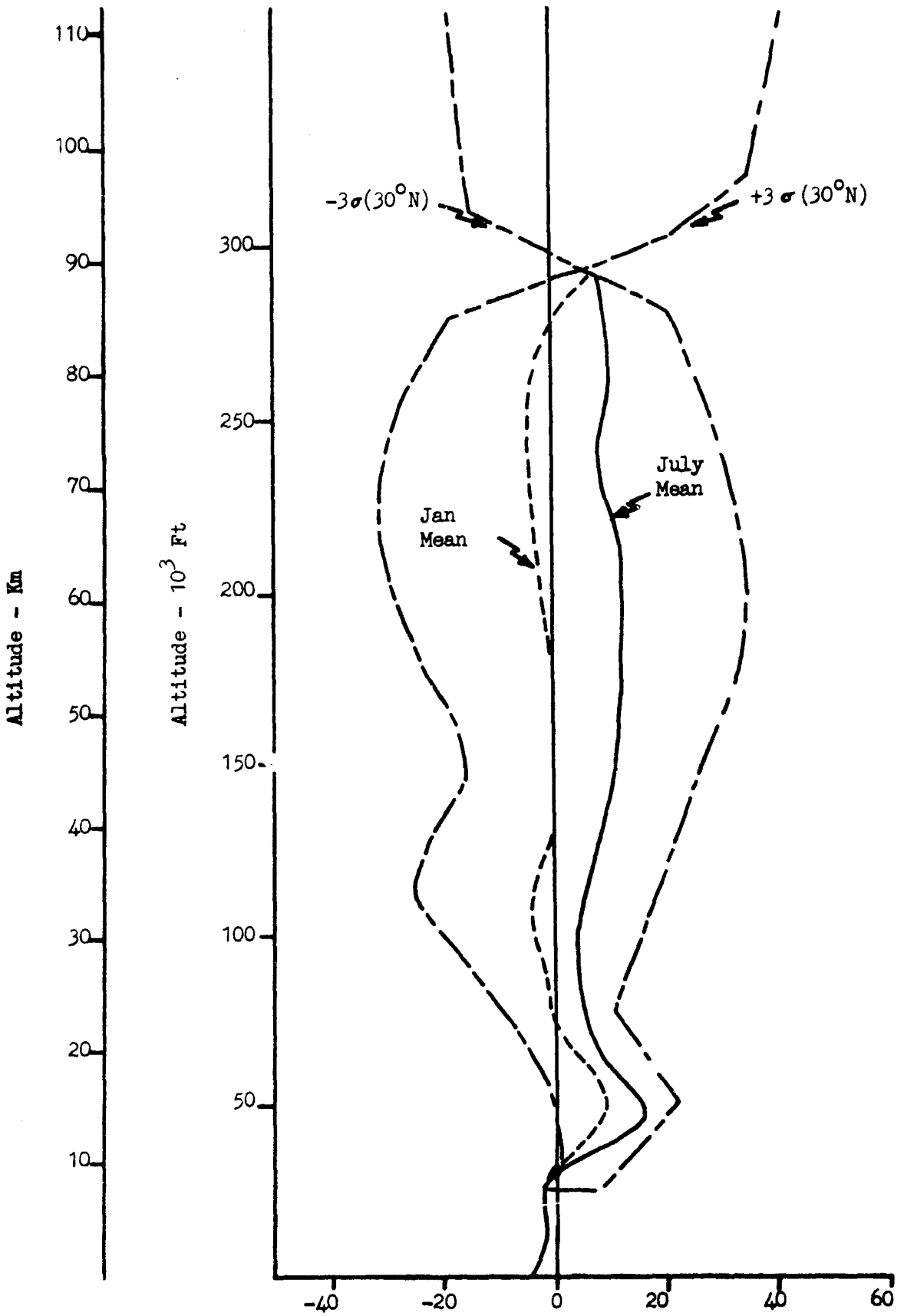Figure 2. - Trim L/D versus c.g. location (CM without protuberances)
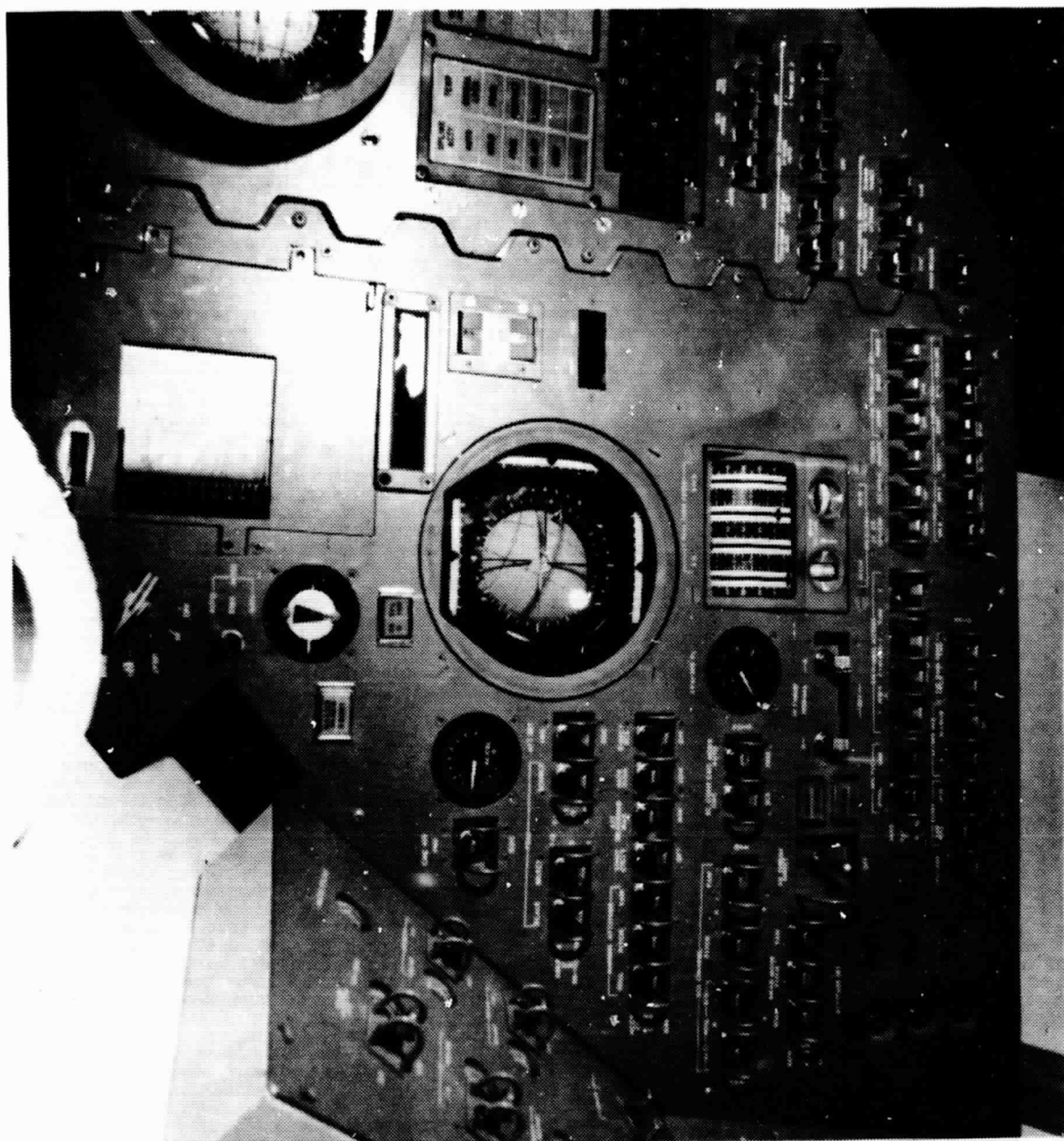
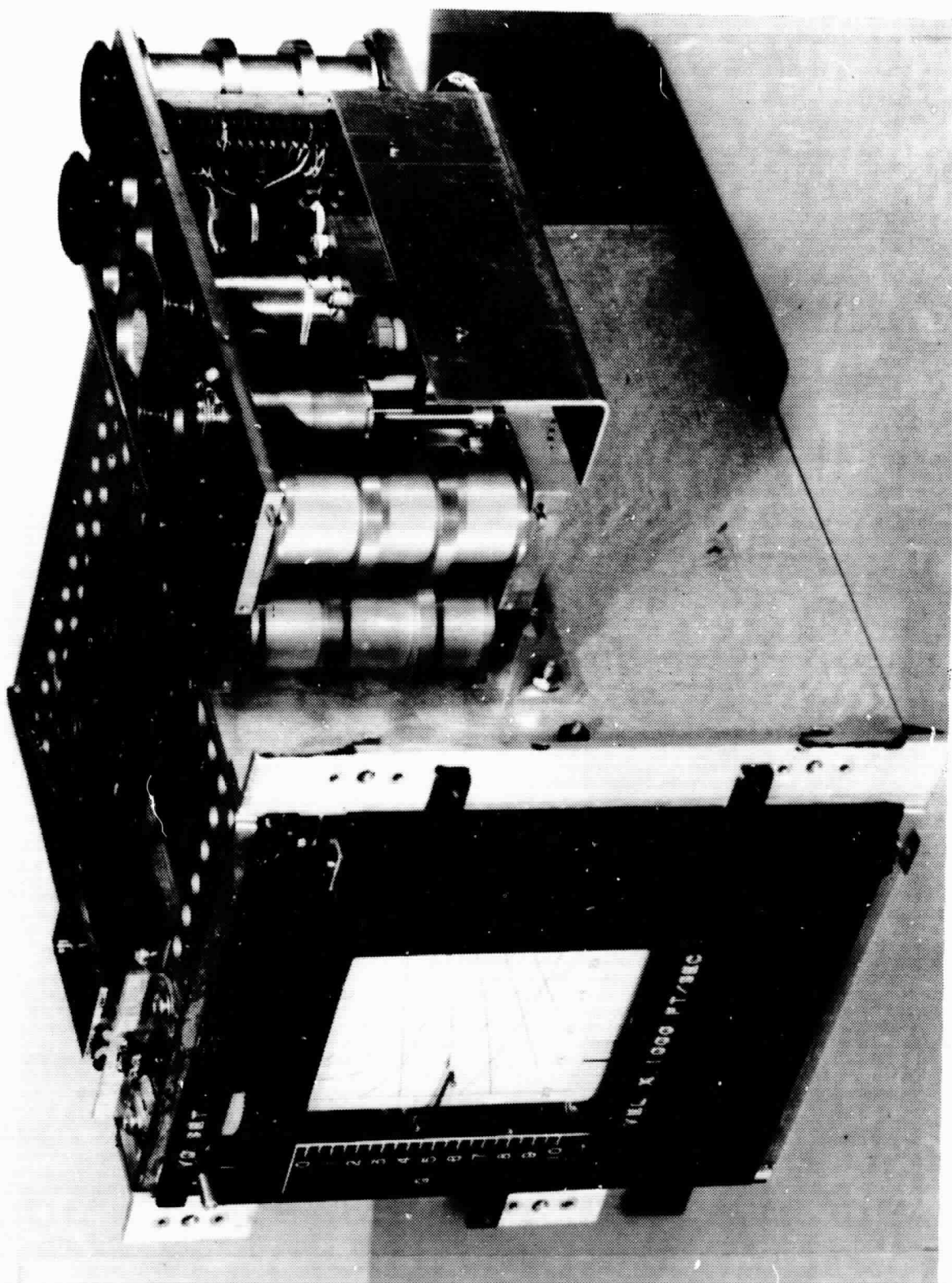Figure 3. - Percent deviation in ρ from 1962 Std. Atmosphere
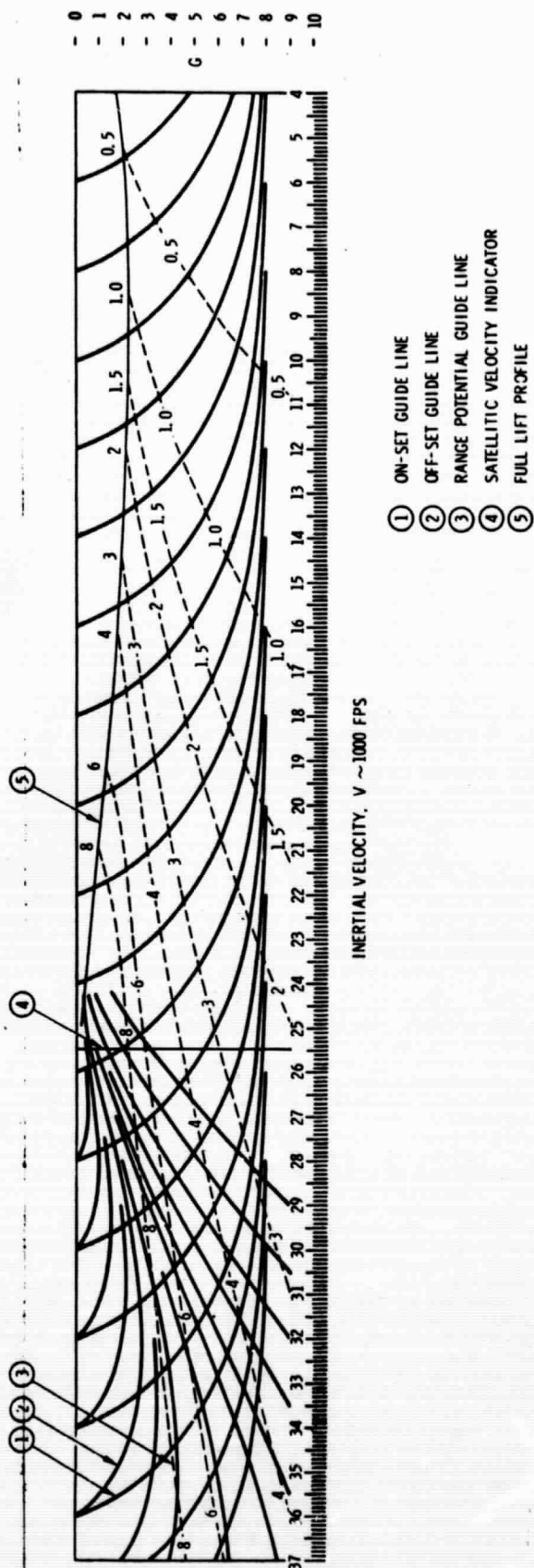
Figure 5. - EMS scroll drive unit used in the simulation

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INERTIAL VELOCITY, V ~1000 FPS

① ON-SET GUIDE LINE
② OFF-SET GUIDE LINE
③ RANGE POTENTIAL GUIDE LINE
④ SATELLITIC VELOCITY INDICATOR
⑤ FULL LIFT PROFILE

Figure 6. - EMS earth orbital non-exit entry pattern

⊗ Indicates initial reentry condition (I.C.)

Mode 2
Lift down to 0.2g then rolling L/D = 0.30
10 % exponential deviated atmosphere
latitude effects included

Mode 1
Operational G and N lift up
limit line L/D = 0.42
10°/o exponential deviated
atmosphere (thin)
latitude effects included

Mode 3
Lift down to 0.2g then lift up
10°/o exponential deviated atmosphere
latitude effects included

RCS target line

SPS target line

Operational 10g undershoot
limit line L/D = 0.42, rolling at
18 deg/sec

Inertial flight–path angle at 400 000 feet altitude, deg

Inertial velocity at 400 000 feet altitude, fps

Figure 7. – Initial conditions of inertial flight-path angle and
inertial velocity

Target Number	Target description	West longitude, deg	North geodetic latitude, deg
4	55° center	65.11	31.87
7	30° center	60.63	31.21
3	70° center	67.86	32.19
1	90° center	70.60	32.43
5	55° South	65.40	31.1
2	80° North	69.40	32.8
6	42° North	62.5	32.3

wt = 13 068 lb
V = 25 700 fps
γ = -1.6°
L/D = .28
h = 400 000 ft
λ = -97.84°
∅ = 31.18°
ψ = 79.469°

O Bank angle, deg
⊗ Target

Maneuver Footprint for IC No. 1
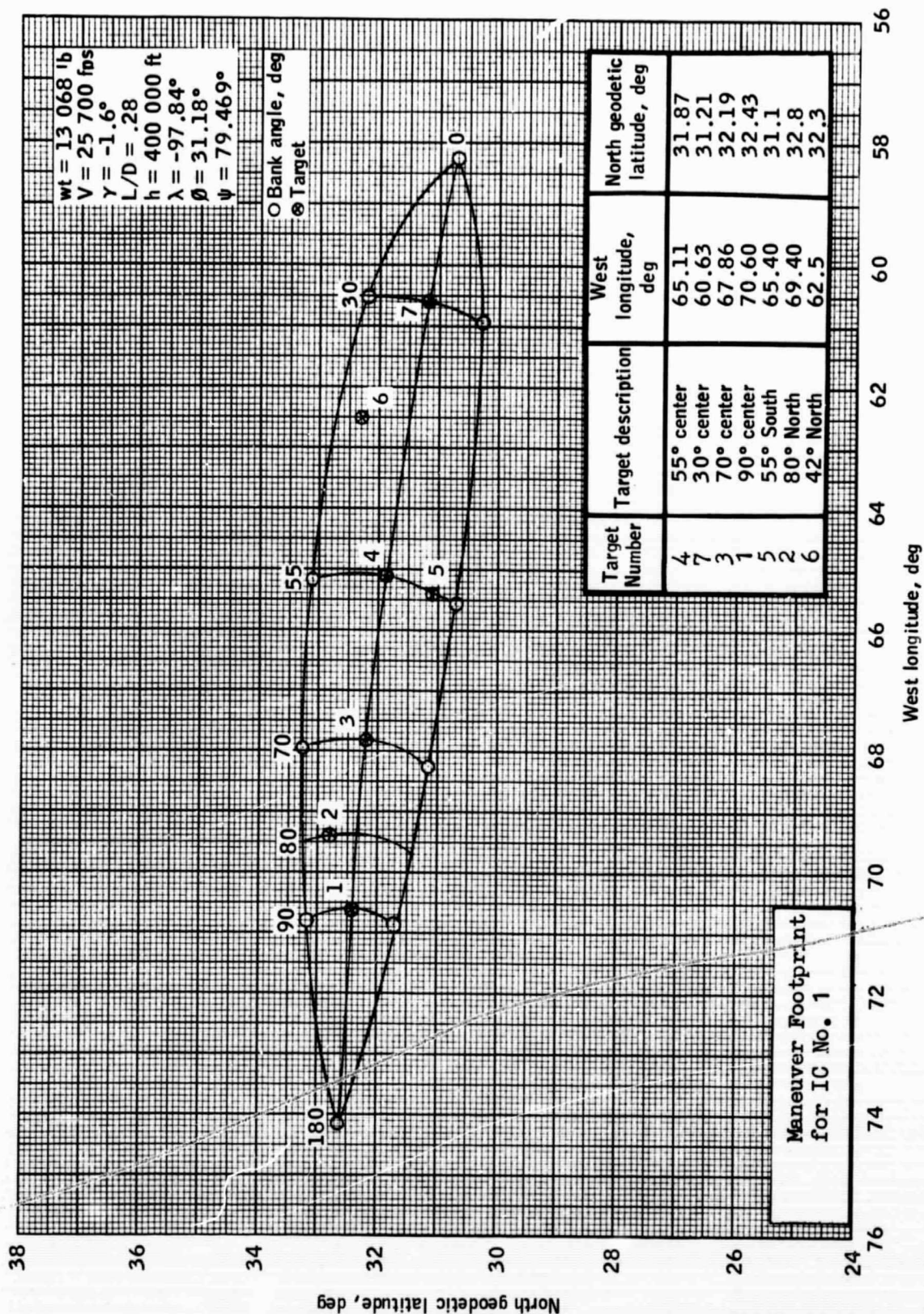
(a) Velocity = 25,700 fps, flight-path angle = 1.6°

Figure 8. - Entry maneuver footprints from various initial conditions
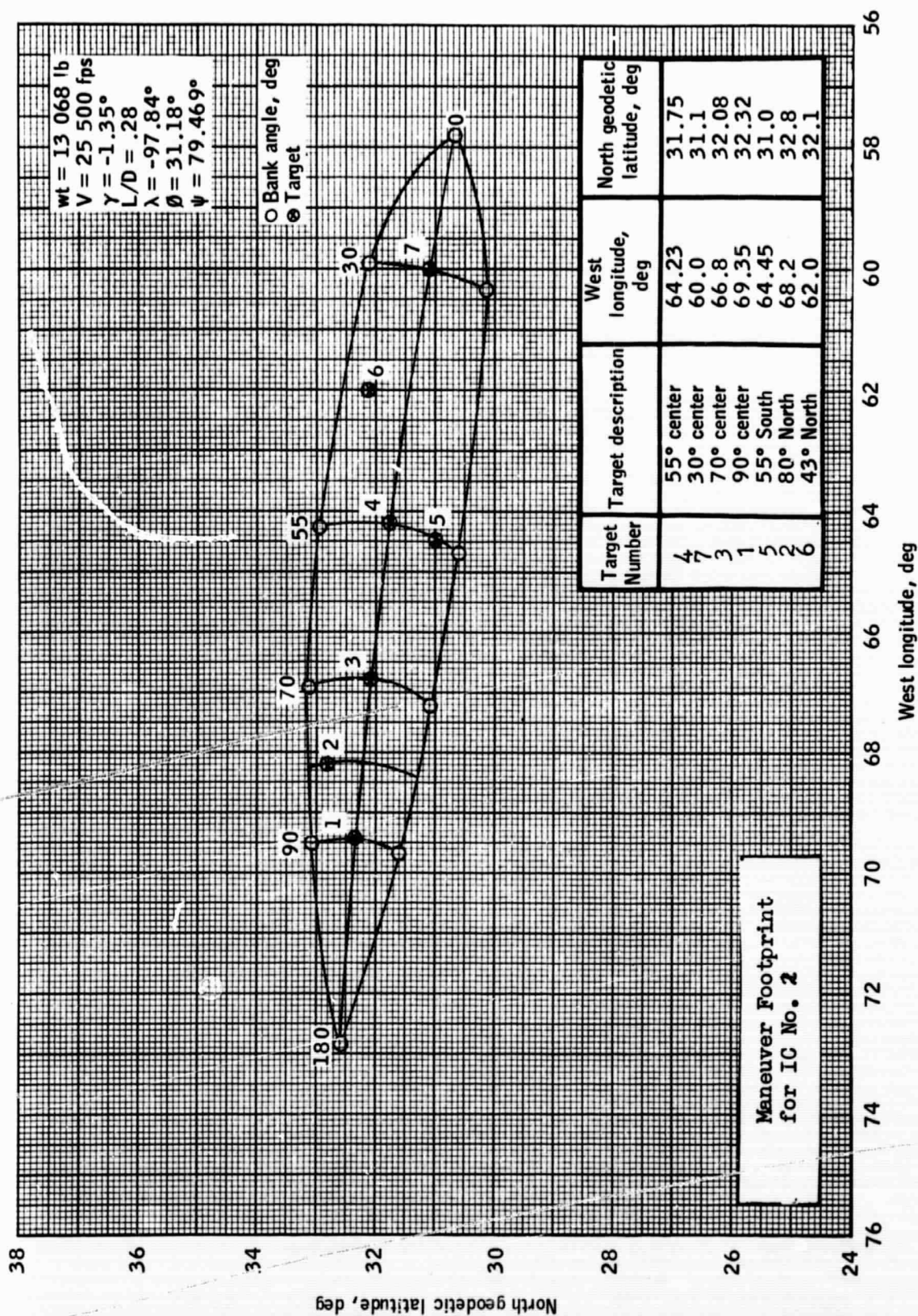
(b) Velocity = 25,500 fps, flight-path angle = -1.35°

Figure 8. - Continued
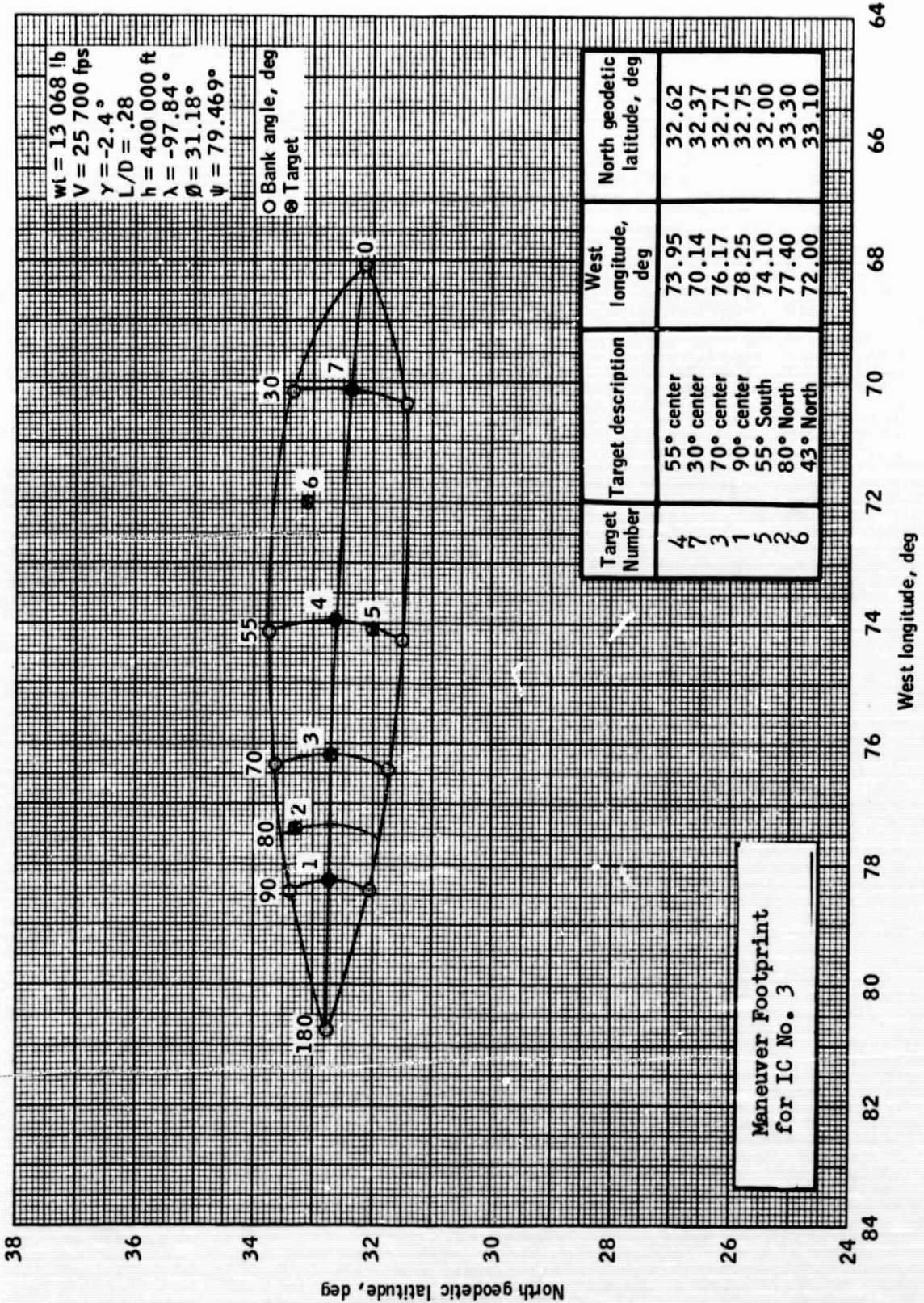
(c) Velocity = 25,700 fps, flight-path angle = -2.4°

Figure 8. - Continued

35d
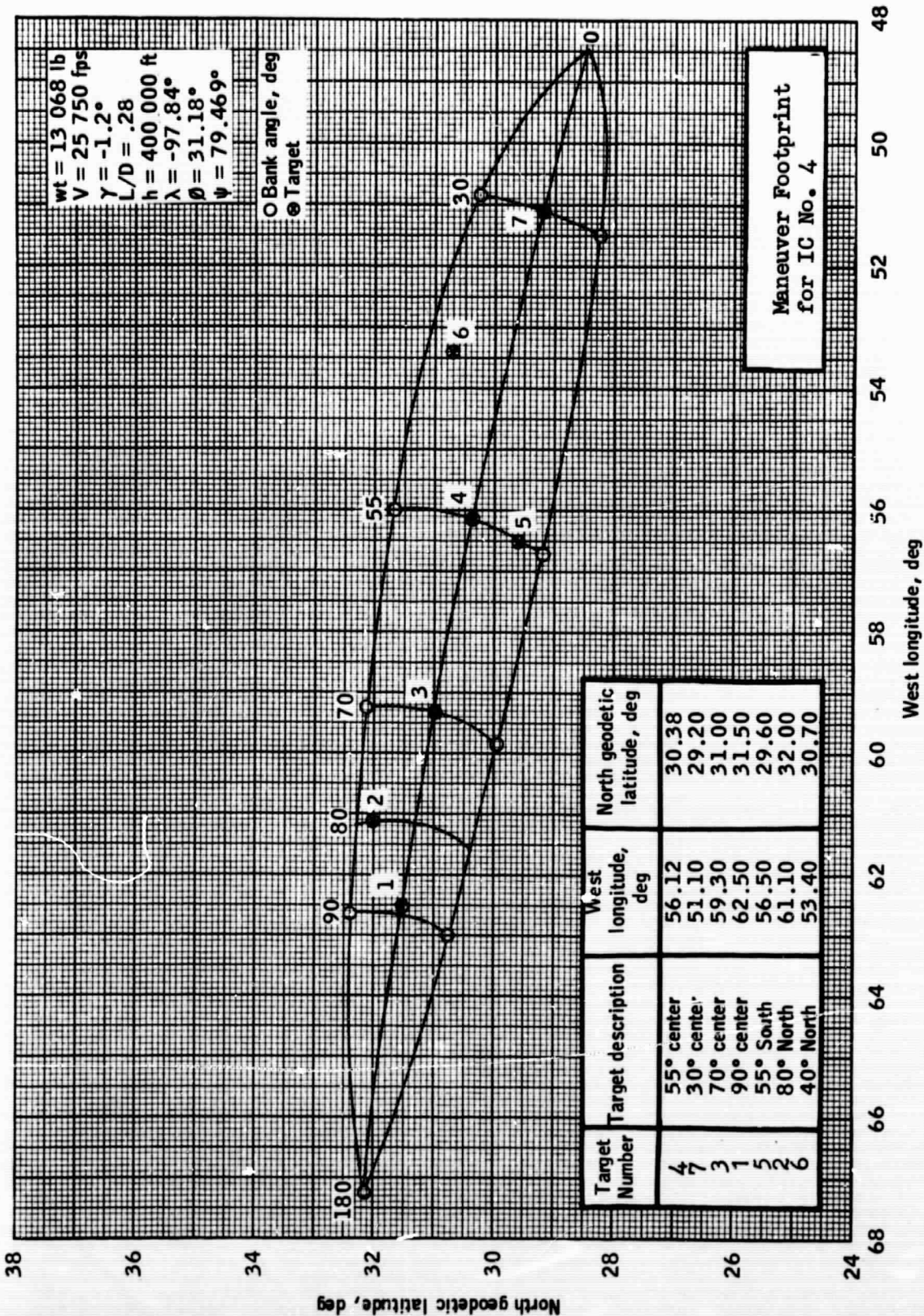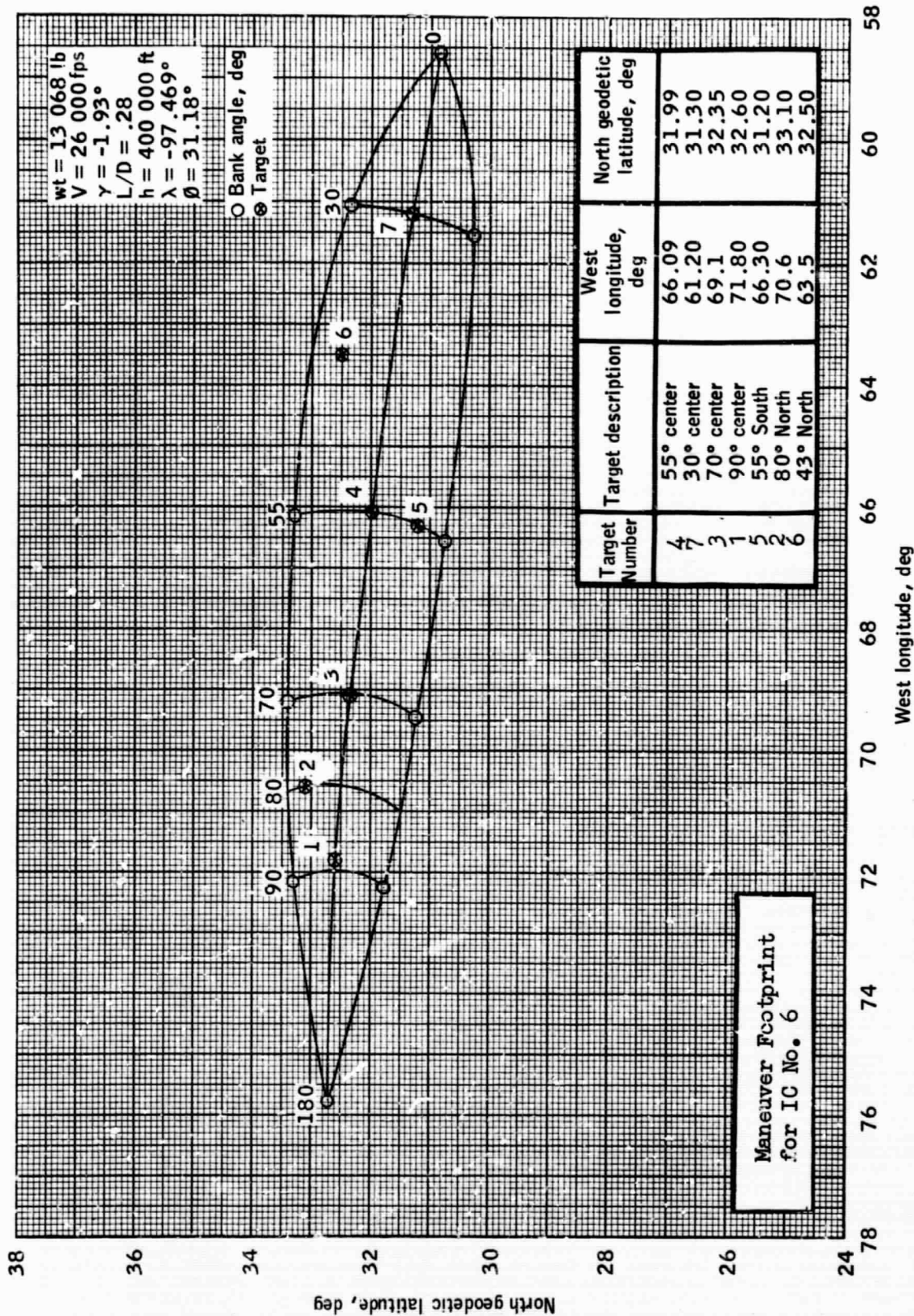

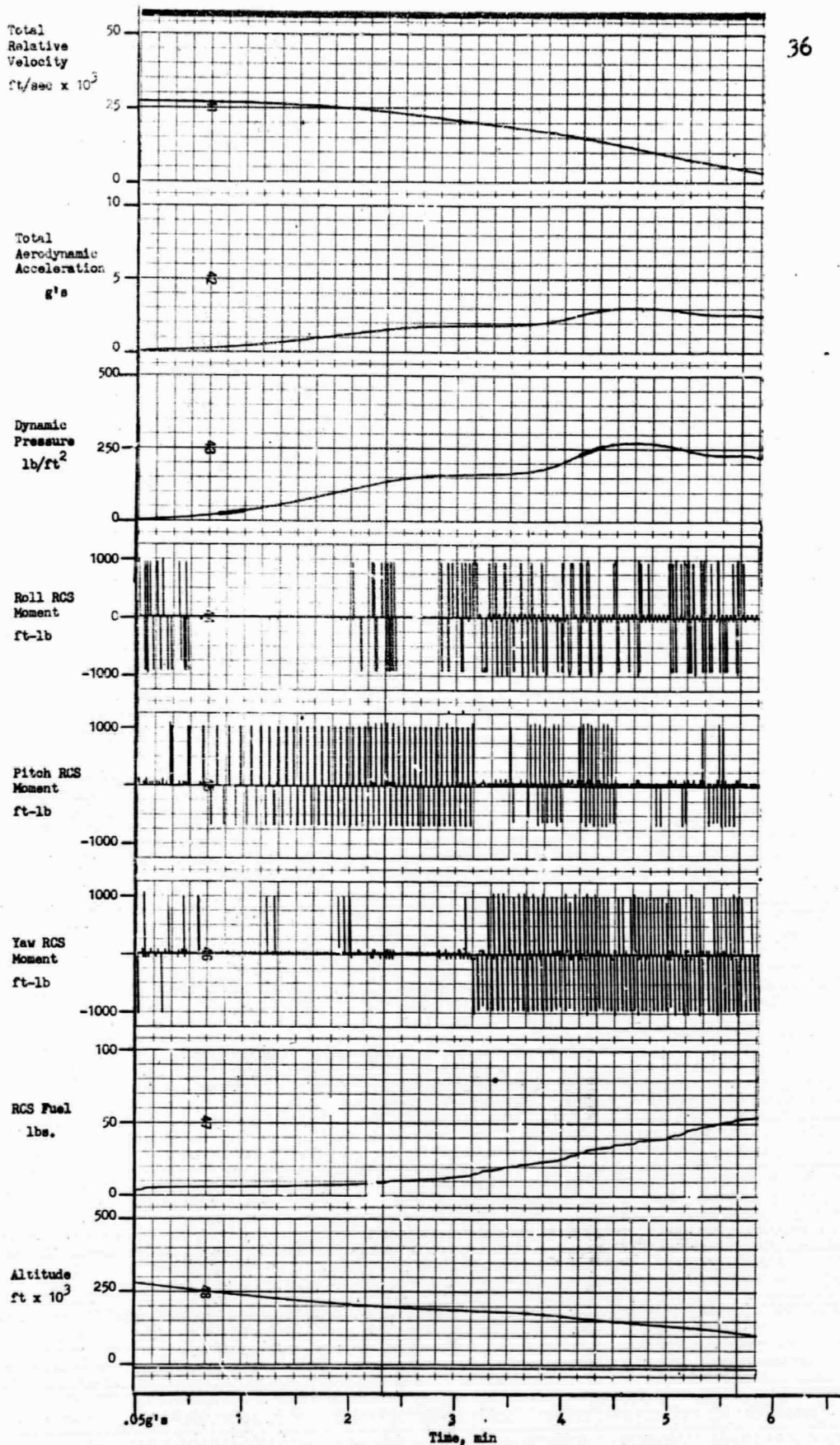(d) Velocity = 25,750 fps, flight-path angle = -1.2°

Figure 8. - Continued
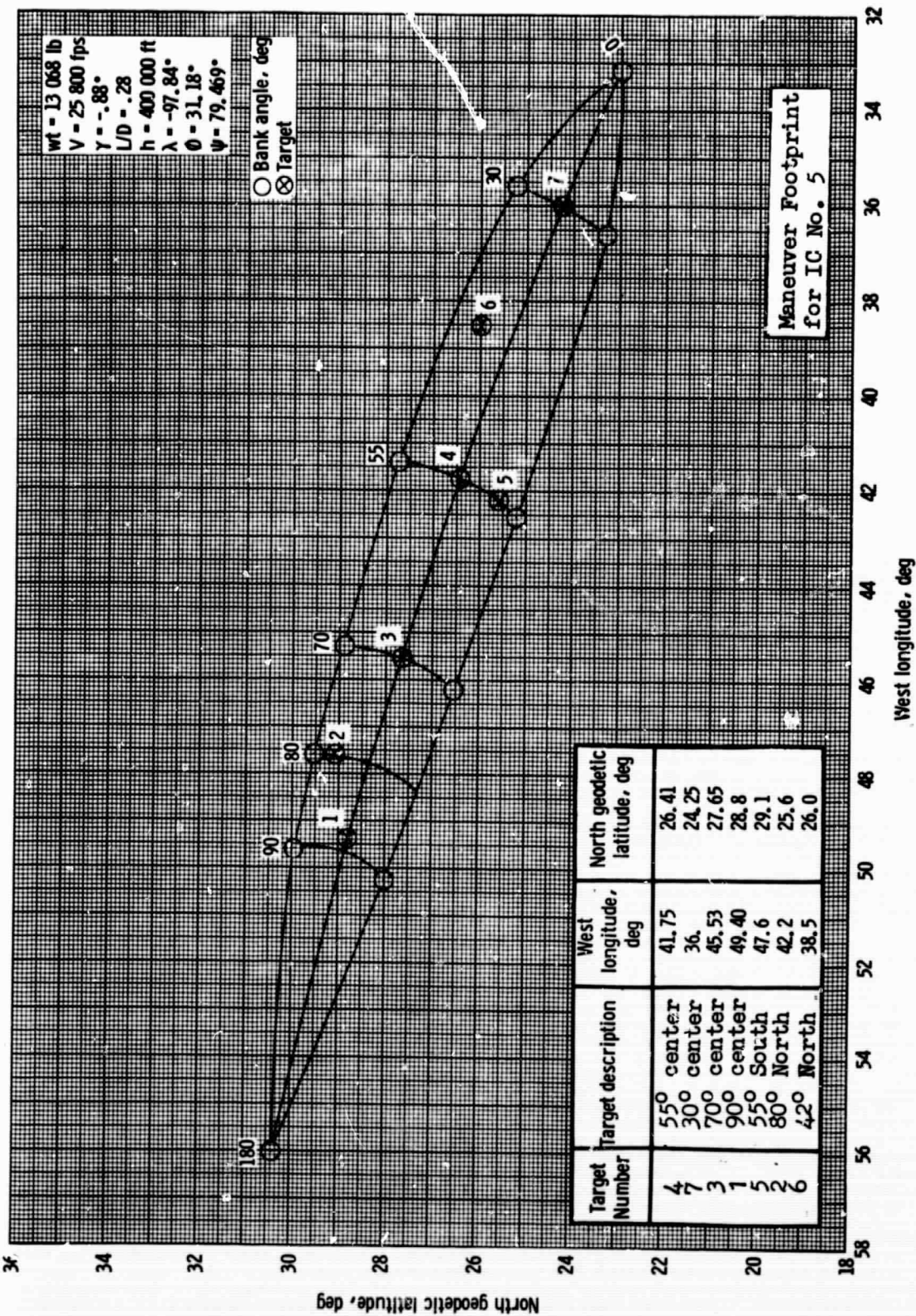
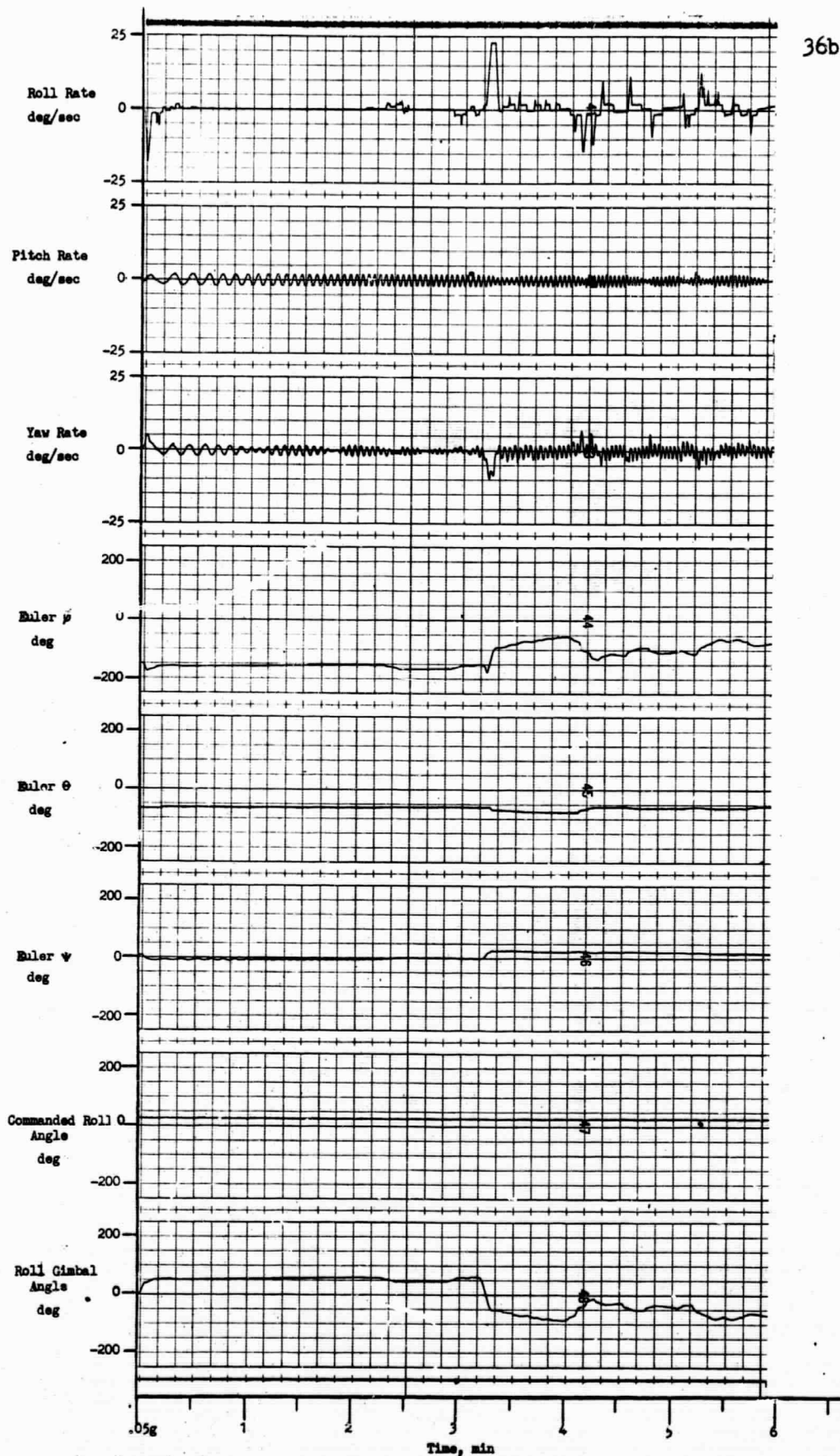(e) Velocity = 25,800 fps, flight-path angle = -.88°

Figure 8. - Continued

(f) Velocity = 26,000 fps, flight-path angle = -1.93°

Figure 8. - Concluded

(a) Eight Channel Recorder (A)

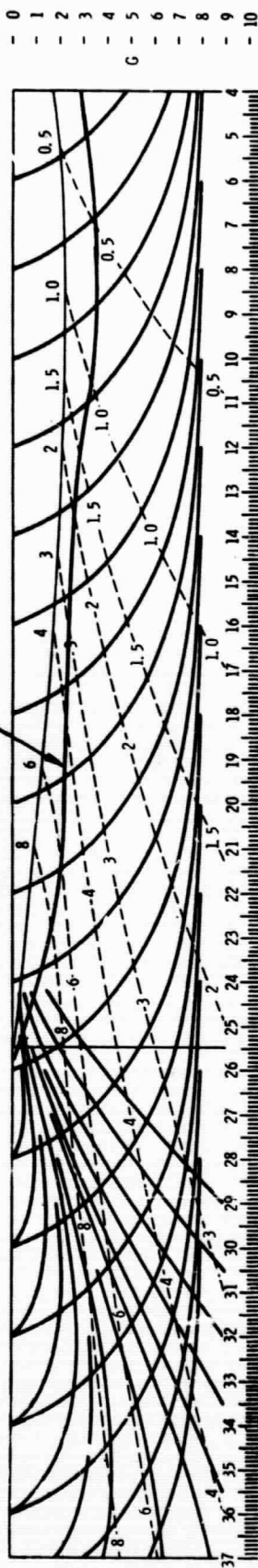Figure 9. - Typical trajectory time history (Hybrid scheme)

(b) Eight Channel Recorder (B)

Figure 9. - Concluded

G vs V Trace

INERTIAL VELOCITY, V ~1000 FPS

Initial Conditions	
Velocity	= 25700 fps
Flight Path Angle	= -1.6°
Altitude	= 400,000 ft

Target Location	
Contour Angle	= 55°
Longitude	= 65.11° W
Latitude	= 31.87° N

Figure 10. - Typical EMS G vs V trace (Hybrid scheme)